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**Hern et al.**

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(54) **MULTIPLE WELL MATCHING WITHIN SUBSURFACE REPRESENTATION**

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(\* ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 220 days.

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(57) **ABSTRACT**

(51) **Int. Cl.**  
**G01V 99/00** (2009.01)  
**G06K 9/62** (2022.01)  
(Continued)

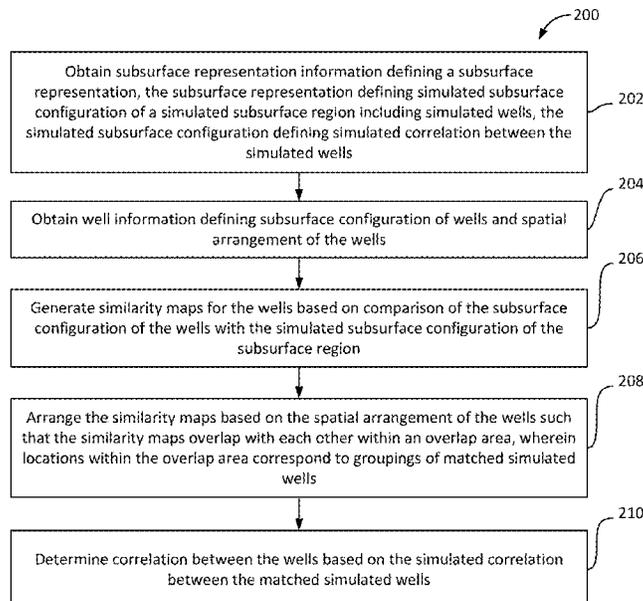
A subsurface representation may define simulated subsurface configuration of a simulated subsurface region. The simulated subsurface region may include simulated wells, and the simulated subsurface configuration may define simulated correlation between the simulated wells. Subsurface configuration of wells may be compared with the simulated subsurface configuration to generate similarity maps for the wells. The similarity maps may be arranged based on spatial arrangements of the wells such that the similarity maps overlap with each other within an overlap area. Locations within the overlap area may correspond to groupings of matched simulated wells. Correlation between the wells may be determined based on the simulated correlation between the matched simulated wells.

(52) **U.S. Cl.**  
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(58) **Field of Classification Search**  
CPC ... G01V 99/005; G06F 30/20; G06F 2113/08; G06K 9/6202; G06K 9/6215; G06V 10/751

See application file for complete search history.

**20 Claims, 14 Drawing Sheets**



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**G06V 10/75** (2022.01)  
**G06F 113/08** (2020.01)

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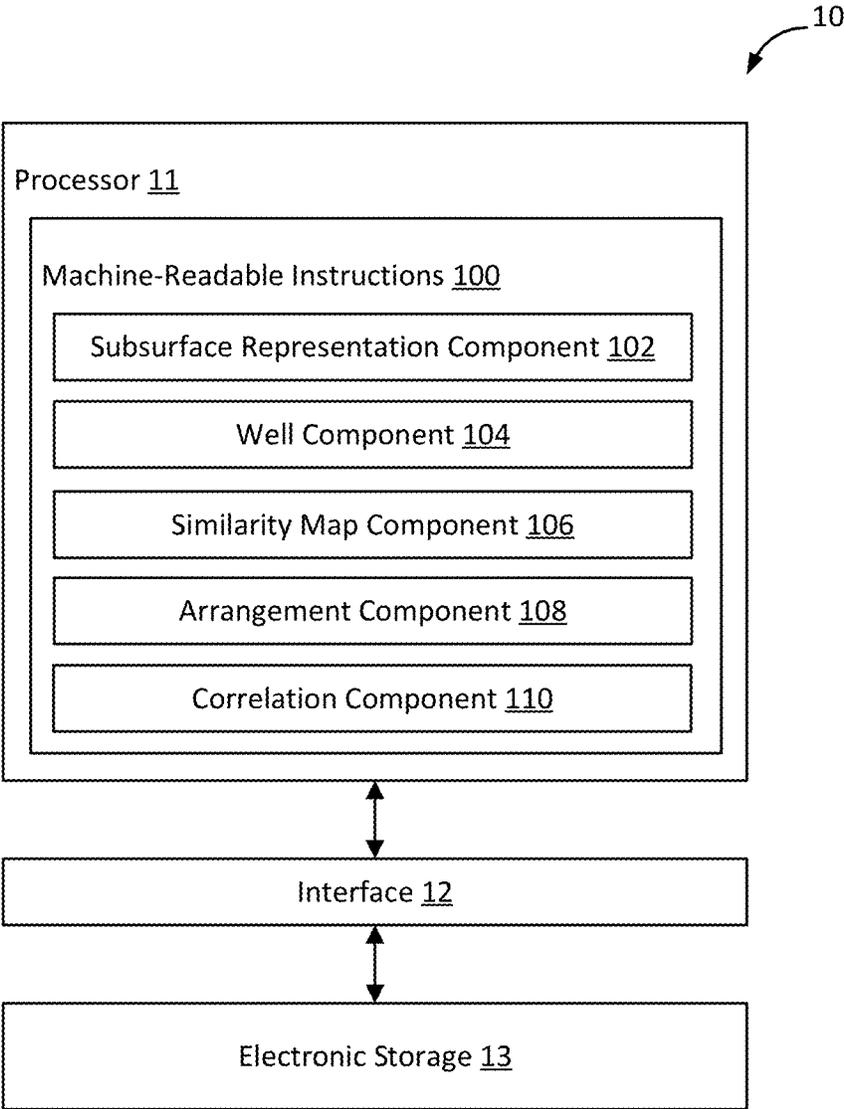
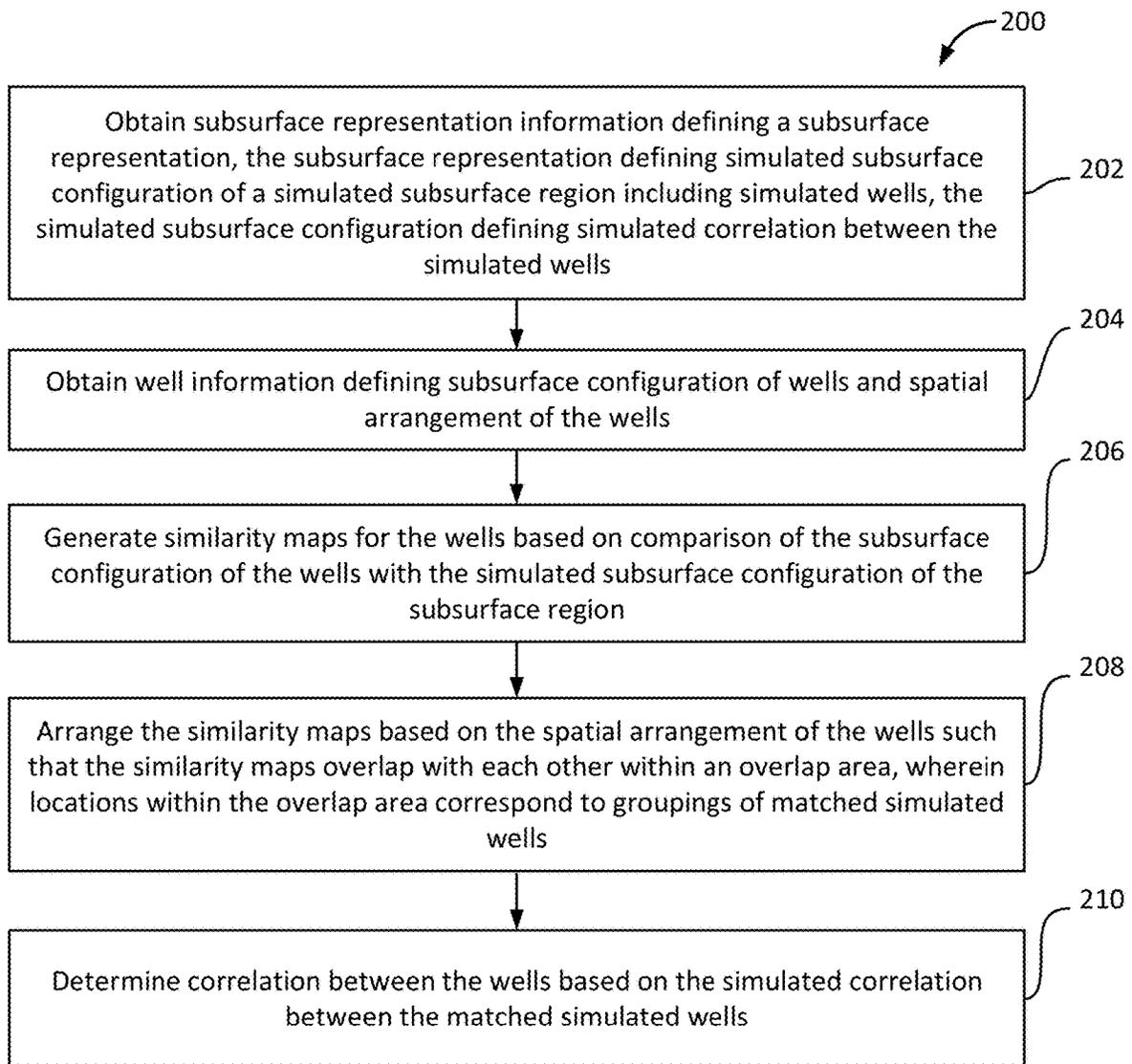


FIG. 1



**FIG. 2**

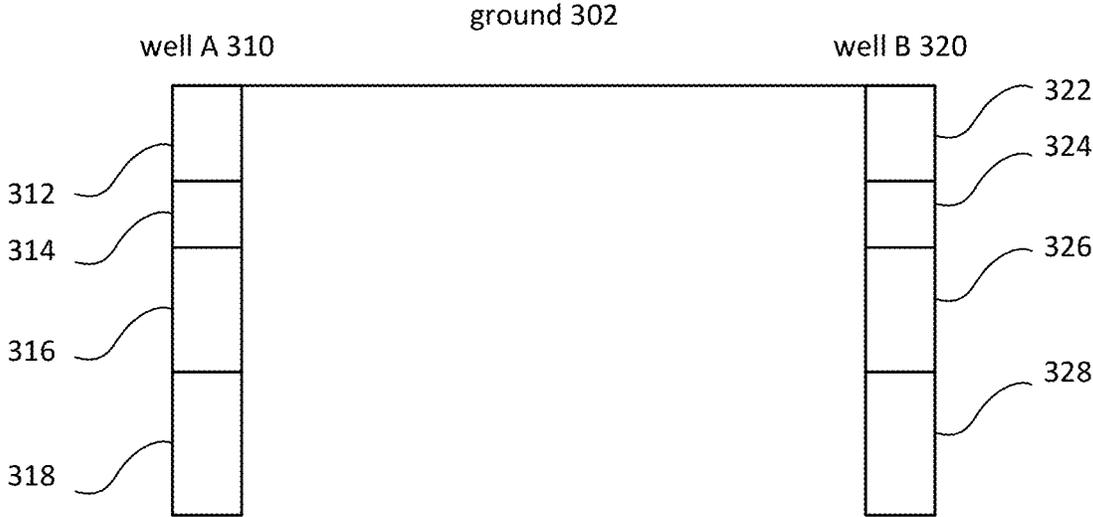


FIG. 3A

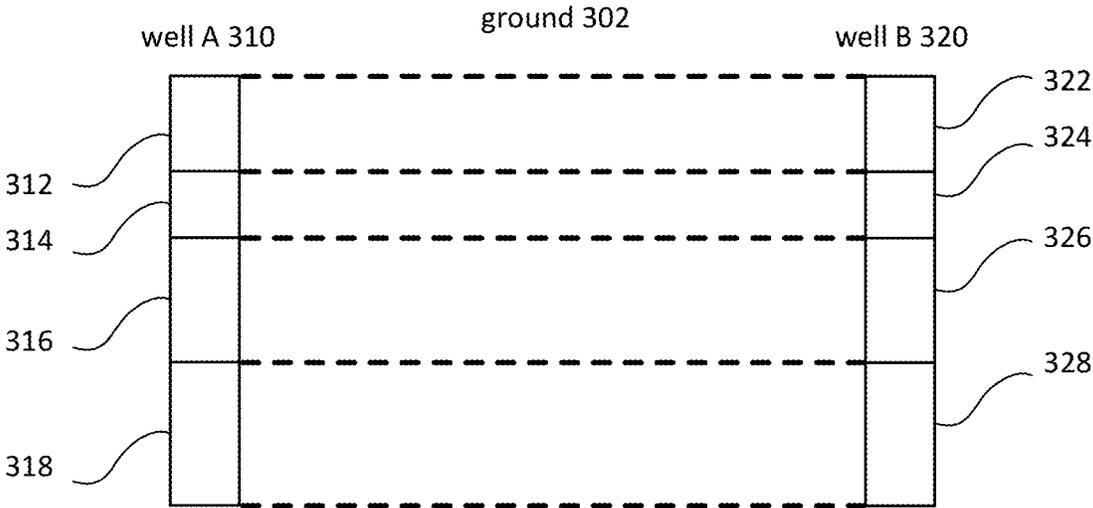


FIG. 3B

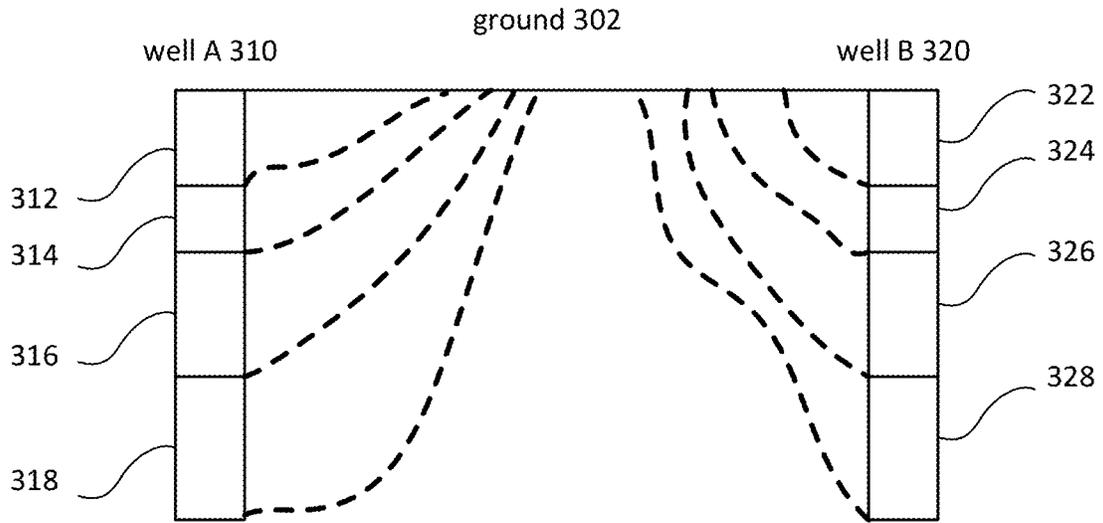


FIG. 3C

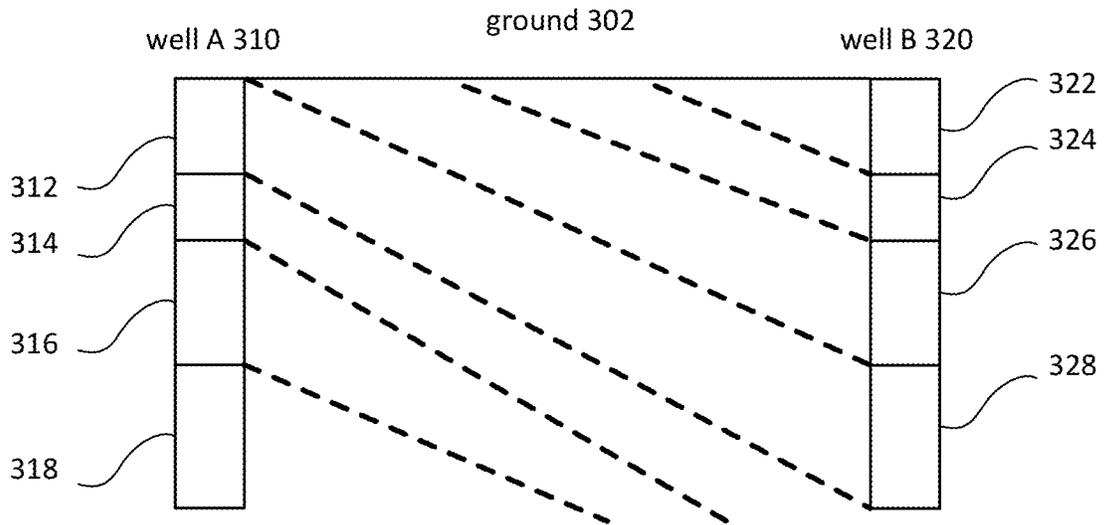


FIG. 3D

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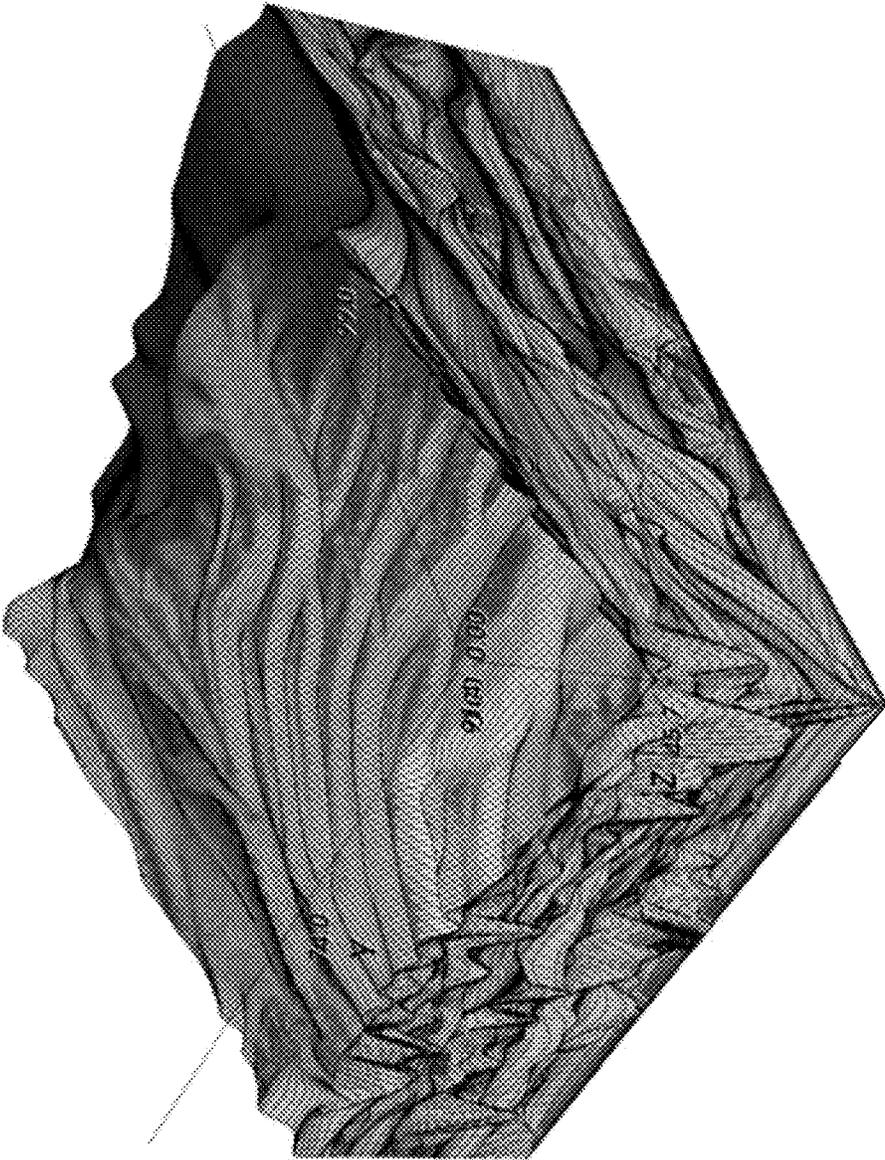


FIG. 4

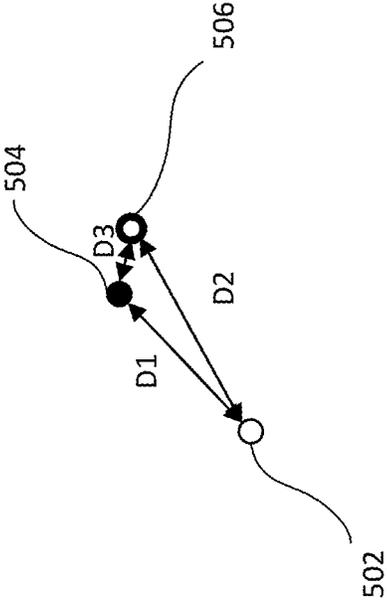


FIG. 5

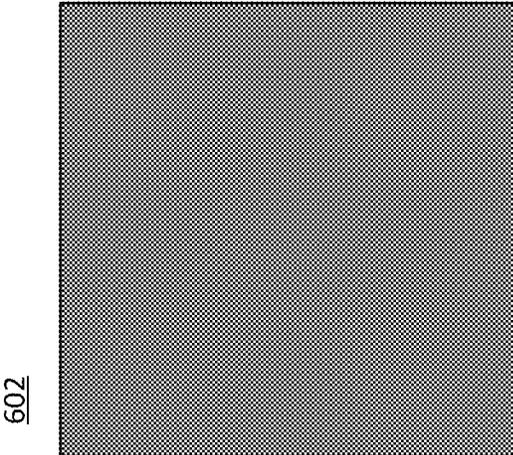
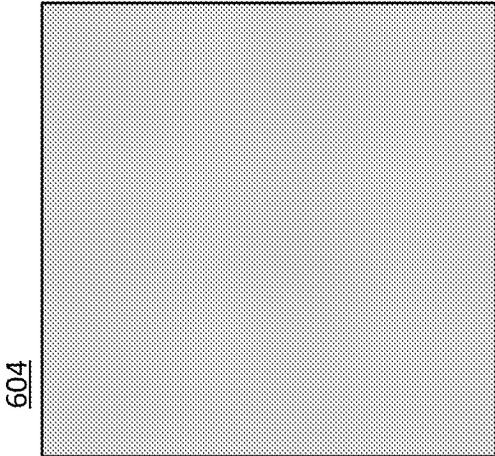
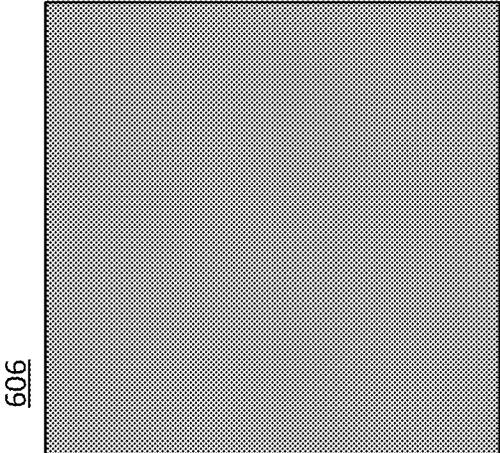


FIG. 6A

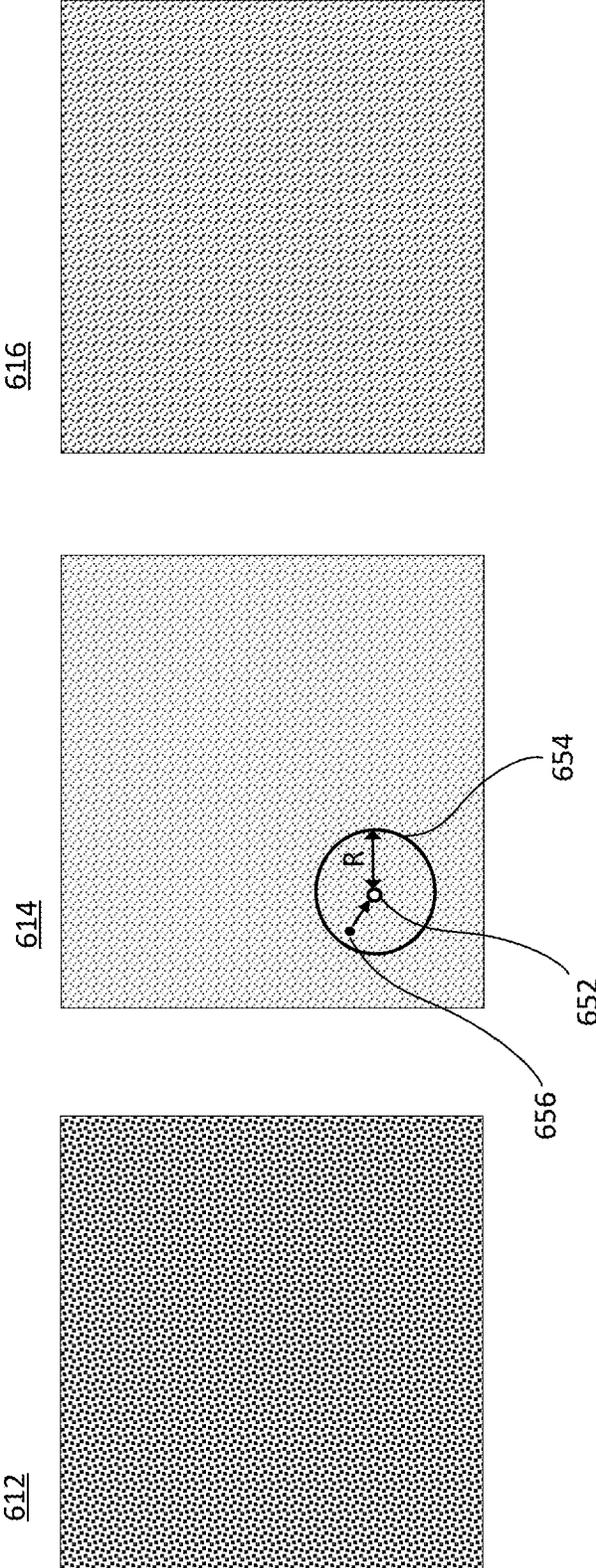
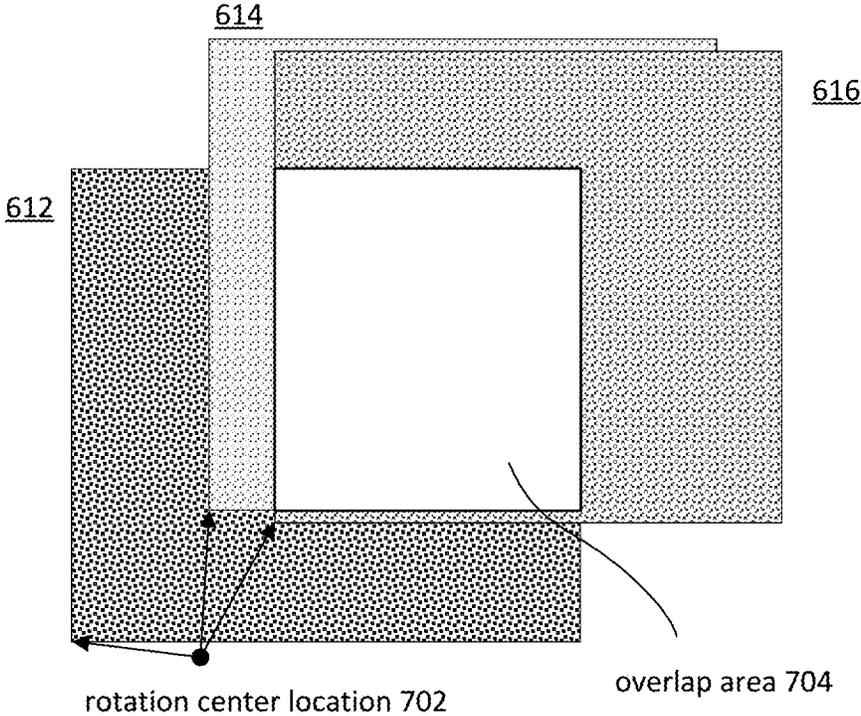
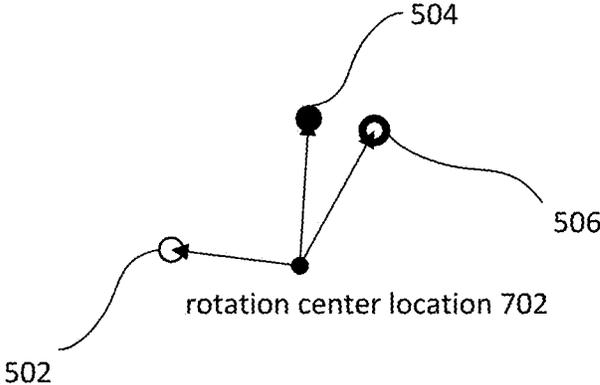
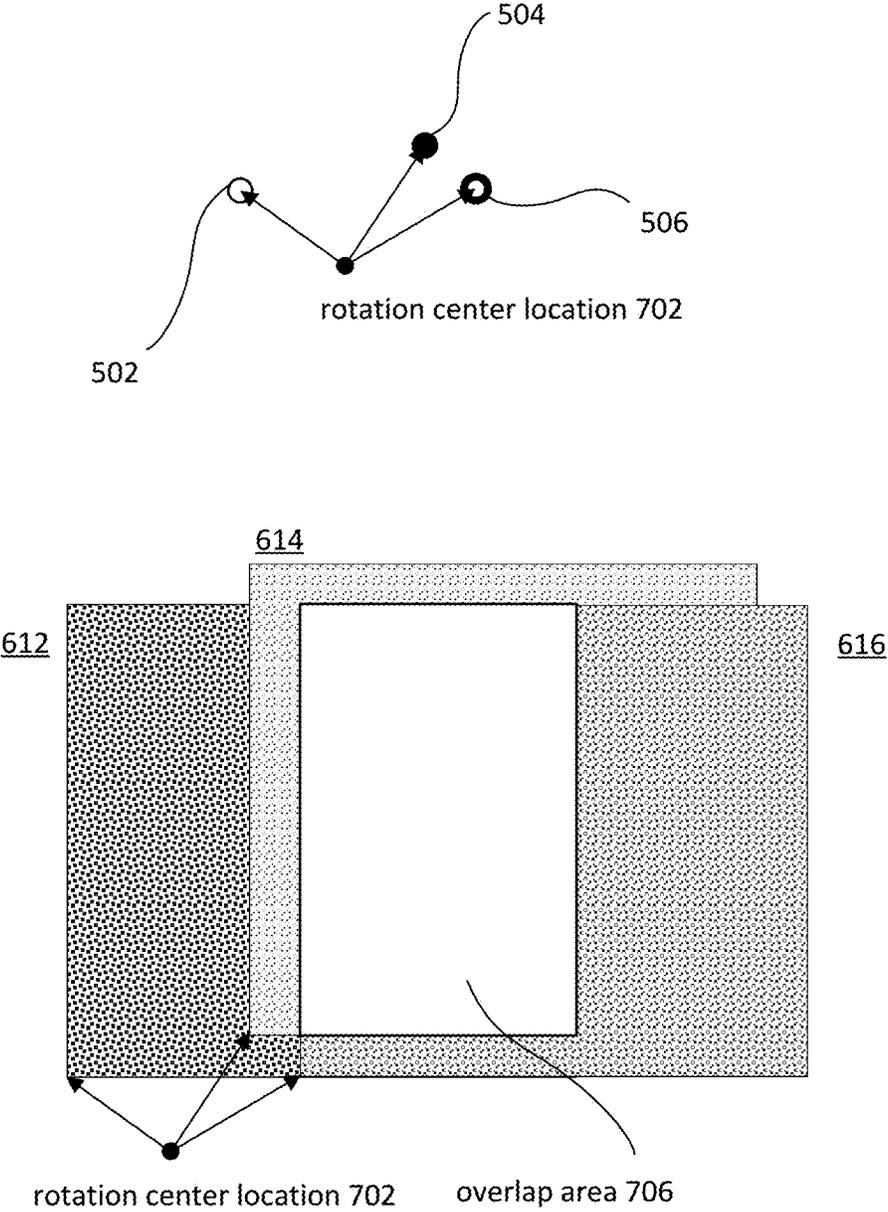


FIG. 6B



**FIG. 7A**



**FIG. 7B**

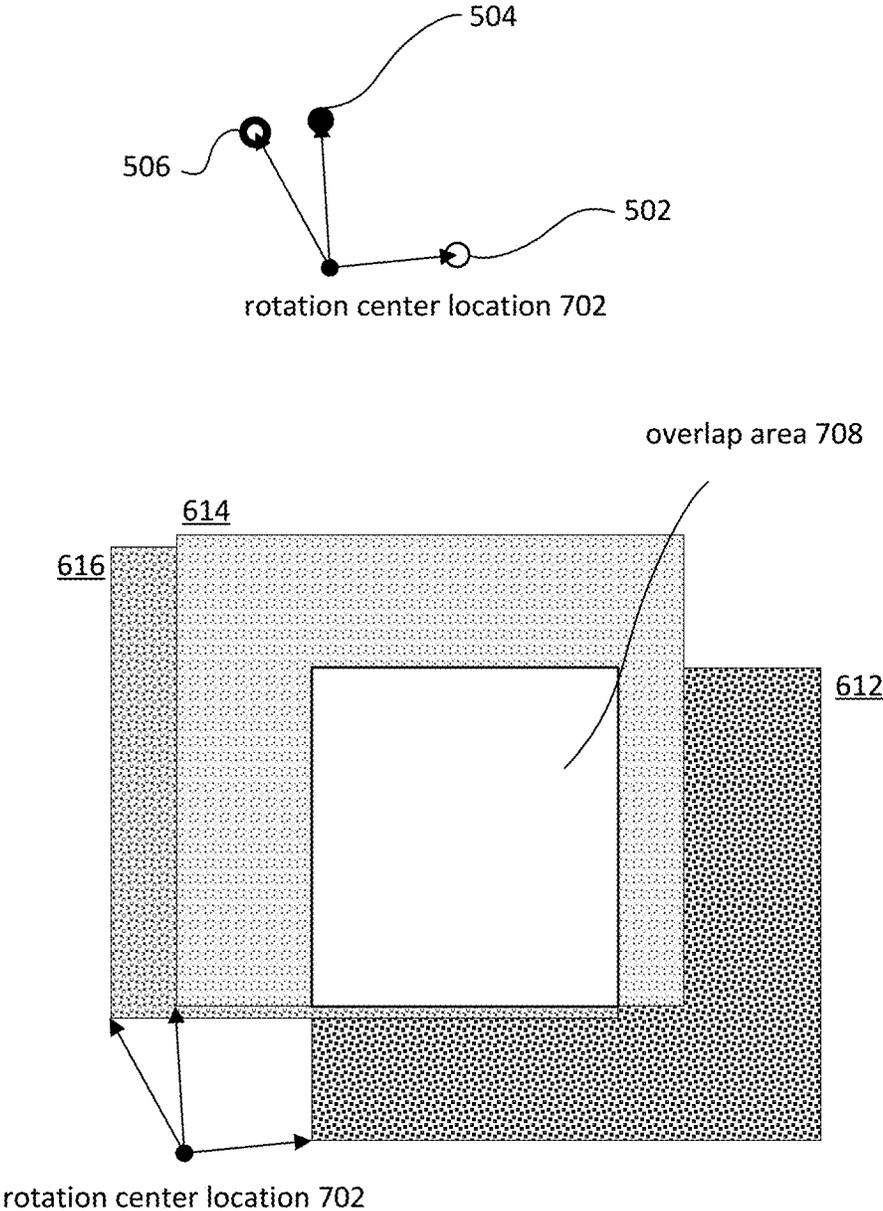


FIG. 7C

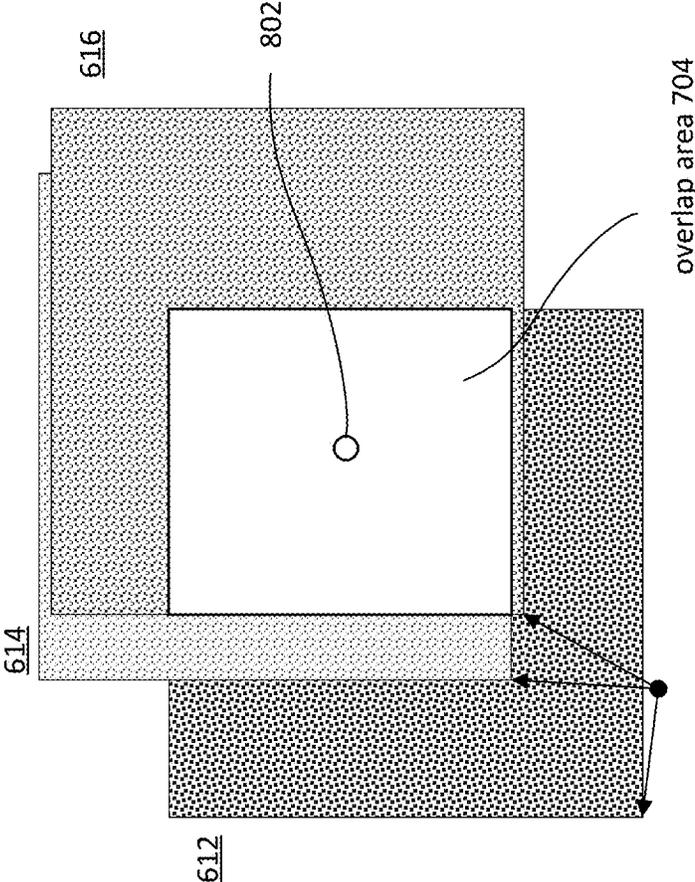


FIG. 8A

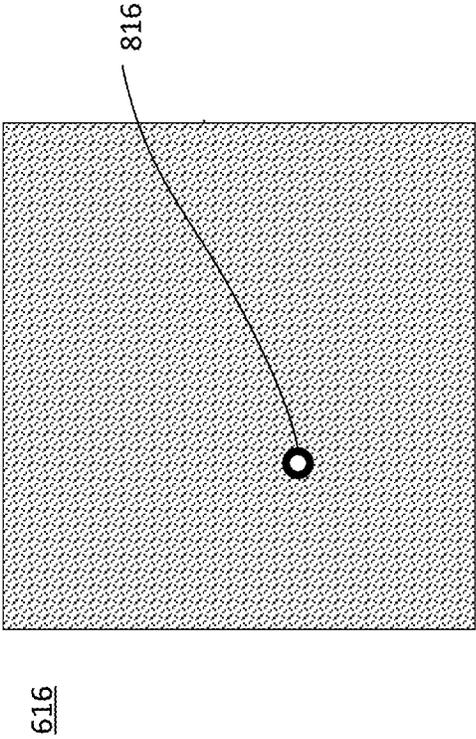
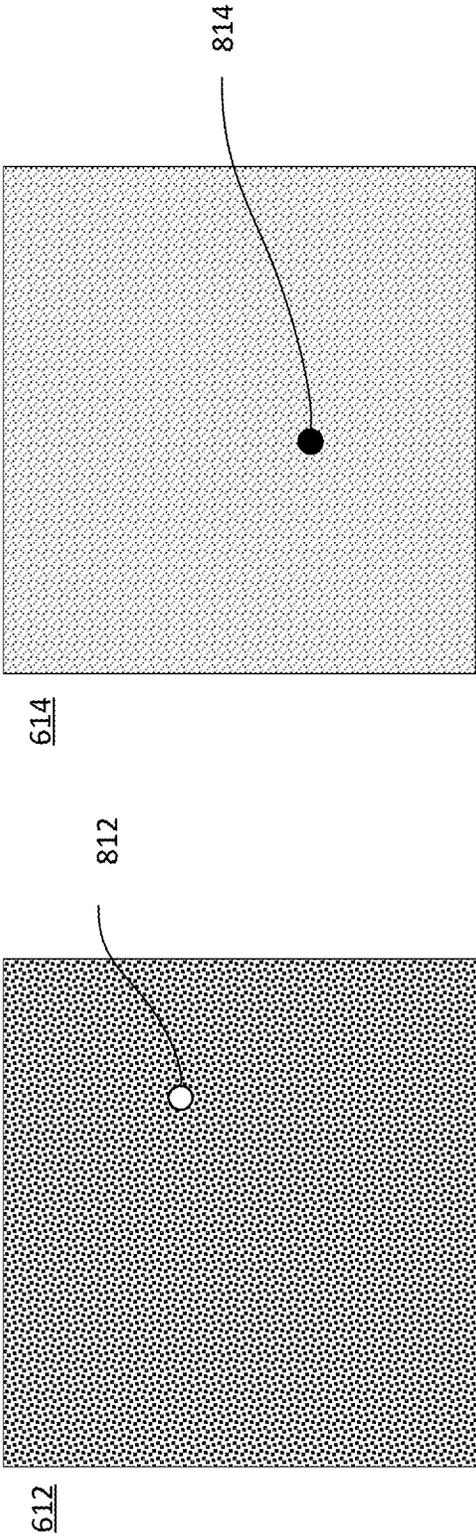


FIG. 8B

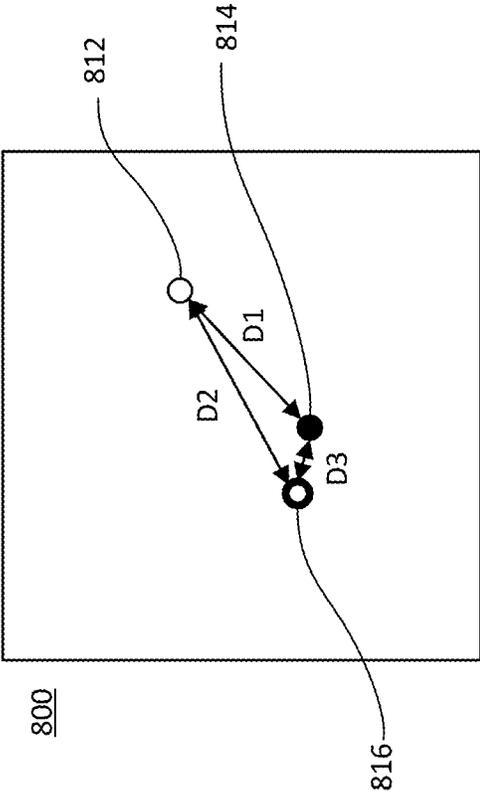


FIG. 8C

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## MULTIPLE WELL MATCHING WITHIN SUBSURFACE REPRESENTATION

### FIELD

The present disclosure relates generally to the field of correlating multiple wells using subsurface representations.

### BACKGROUND

Correlation between wells may be estimated using simulated correlation between simulated wells inside subsurface representation. Simulated wells may be matched to the wells, and the simulated correlation between the matched simulated wells may be used to determine the correlation between the wells. Increase in number of wells to be matched within the subsurface representation may exponentially increase computational complexity of search to match simulated wells.

### SUMMARY

This disclosure relates to correlating multiple wells. Subsurface representation information, well information, and/or other information may be obtained. The subsurface representation information may define one or more subsurface representations. A subsurface representation may define simulated subsurface configuration of a simulated subsurface region including simulated wells. The simulated subsurface configuration of the simulated subsurface region may define simulated correlation between the simulated wells. The well information may define subsurface configuration of wells and spatial arrangement of the wells.

Similarity maps for the wells may be generated based on comparison of the subsurface configuration of the wells with the simulated subsurface configuration of the simulated subsurface region and/or other information. Individual similarity maps may characterize extent of similarity between individual ones of the wells and different locations within the simulated subsurface region. The similarity maps may be arranged based on the spatial arrangement of the wells and/or other information. The similarity maps may be arranged such that the similarity maps overlap with each other within an overlap area. Locations within the overlap area may correspond to groupings of matched simulated wells. Individual groupings may include a matched simulated well for individual ones of the wells. Correlation between the wells may be determined based on the simulated correlation between the matched simulated wells and/or other information.

A system that correlates multiple wells may include one or more electronic storage, one or more processors and/or other components. The electronic storage may store subsurface representation information, information relating to subsurface representation, information relating to simulated subsurface configuration, information relating to simulated subsurface region, information relating to simulated well, well information, information relating wells, information relating to subsurface configuration of wells, information relating to spatial arrangement of wells, information relating to similarity maps, information relating to arrangement of similarity maps, information relating to matched simulated wells, information relating to correlation between wells, and/or other information.

The processor(s) may be configured by machine-readable instructions. Executing the machine-readable instructions may cause the processor(s) to facilitate correlating multiple

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wells. The machine-readable instructions may include one or more computer program components. The computer program components may include one or more of a subsurface representation component, a well component, a similarity map component, an arrangement component, a correlation component, and/or other computer program components.

The subsurface representation component may be configured to obtain subsurface representation information and/or other information. The subsurface representation information may define one or more subsurface representations. A subsurface representation may define simulated subsurface configuration of a simulated subsurface region. The simulated subsurface region may include simulated wells. The simulated subsurface configuration of the simulated subsurface region may define simulated correlation between the simulated wells.

In some implementations, a subsurface representation may include a computational stratigraphy model representation, and the correlation between the wells may include chrono-sequence stratigraphic correlation.

The well component may be configured to obtain well information and/or other information. The well information may define subsurface configuration of wells and spatial arrangement of the wells.

The similarity map component may be configured to generate similarity maps for the wells. The similarity maps may be generated based on comparison of the subsurface configuration of the wells with the simulated subsurface configuration of the simulated subsurface region, and/or other information. Individual similarity maps may characterize extent of similarity between individual ones of the wells and different locations within the simulated subsurface region.

In some implementations, generation of the similarity maps may include determination of preferred well-matching locations for portions of the similarity maps. In some implementations, the preferred well-matching locations may be determined based on the extent of similarity between individual ones of the wells and different locations within the portions of the similarity maps, and/or other information.

In some implementations, the portions of the similarity maps may include regions of the similarity map within boundaries for corresponding locations. In some implementations, the boundaries for the corresponding locations may be defined by one or more symmetrical shapes including the corresponding locations. In some implementations, a shape including the corresponding locations may be defined by a radius around the corresponding locations.

The arrangement component may be configured to arrange the similarity maps based on the spatial arrangement of the wells and/or other information. The similarity maps may be arranged such that the similarity maps overlap with each other within an overlap area. Locations within the overlap area may correspond to groupings of matched simulated wells. Individual groupings of matched simulated wells may include a matched simulated well for individual ones of the wells.

In some implementations, the arrangement of the similarity maps may include the similarity maps displaced from a rotation center location to match displacement of corresponding wells from the rotation center location. In some implementations, rotation of the similarity maps about the rotation center location may change the arrangement of the similarity maps and the overlap area covered by the similarity maps. Changes to the overlap area may result in

changes to the groupings of matched simulated wells corresponding to the locations within the overlap area.

In some implementations, the spatial arrangement of the wells may be changed by flipping locations of the wells about a line. Changes to the spatial arrangement of the wells may result in changes to the arrangement of the similarity maps.

The correlation component may be configured to determine correlation between the wells based on the simulated correlation between the matched simulated wells and/or other information.

These and other objects, features, and characteristics of the system and/or method disclosed herein, as well as the methods of operation and functions of the related elements of structure and the combination of parts and economies of manufacture, will become more apparent upon consideration of the following description and the appended claims with reference to the accompanying drawings, all of which form a part of this specification, wherein like reference numerals designate corresponding parts in the various figures. It is to be expressly understood, however, that the drawings are for the purpose of illustration and description only and are not intended as a definition of the limits of the invention. As used in the specification and in the claims, the singular form of "a," "an," and "the" include plural referents unless the context clearly dictates otherwise.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates an example system that correlates multiple wells.

FIG. 2 illustrates an example method for correlating multiple wells.

FIGS. 3A-3D illustrate example segments of two wells.

FIG. 4 illustrates an example subsurface representation.

FIG. 5 illustrates an example spatial arrangement of wells.

FIG. 6A illustrates example similarity maps.

FIG. 6B illustrates example preferred well-matching locations for portions of similarity maps.

FIGS. 7A, 7B, and 7C illustrate example arrangement of similarity maps.

FIGS. 8A, 8B, and 8C illustrate an example grouping of matched simulated wells.

#### DETAILED DESCRIPTION

The present disclosure relates to correlating multiple wells. A subsurface representation may define simulated subsurface configuration of a simulated subsurface region. The simulated subsurface region may include simulated wells, and the simulated subsurface configuration may define simulated correlation between the simulated wells. Subsurface configuration of wells may be compared with the simulated subsurface configuration to generate similarity maps for the wells. The similarity maps may be arranged based on spatial arrangements of the wells such that the similarity maps overlap with each other within an overlap area. Locations within the overlap area may correspond to groupings of matched simulated wells. Correlation between the wells may be determined based on the simulated correlation between the matched simulated wells.

The methods and systems of the present disclosure may be implemented by and/or in a computing system, such as a system 10 shown in FIG. 1. The system 10 may include one or more of a processor 11, an interface 12 (e.g., bus, wireless interface), an electronic storage 13, and/or other components. Subsurface representation information, well informa-

tion, and/or other information may be obtained by the processor 11. The subsurface representation information may define one or more subsurface representations. A subsurface representation may define simulated subsurface configuration of a simulated subsurface region including simulated wells. The simulated subsurface configuration of the simulated subsurface region may define simulated correlation between the simulated wells. The well information may define subsurface configuration of wells and spatial arrangement of the wells.

Similarity maps for the wells may be generated by the processor 11 based on comparison of the subsurface configuration of the wells with the simulated subsurface configuration of the simulated subsurface region and/or other information. Individual similarity maps may characterize extent of similarity between individual ones of the wells and different locations within the simulated subsurface region. The similarity maps may be arranged by the processor 11 based on the spatial arrangement of the wells and/or other information. The similarity maps may be arranged such that the similarity maps overlap with each other within an overlap area. Locations within the overlap area may correspond to groupings of matched simulated wells. Individual groupings may include a matched simulated well for individual ones of the wells. Correlation between the wells may be determined by the processor 11 based on the simulated correlation between the matched simulated wells and/or other information.

A well may refer to a hole or a tunnel in the ground. A well may be drilled in the ground for exploration and/or recovery of natural resources in the ground. For example, a well may be drilled in the ground to aid in extraction of petrochemical fluid (e.g., oil, gas, petroleum, fossil fuel). A well may be drilled in one or more directions. For example, a well may include a vertical well, a horizontal well, a deviated well, and/or other type of well.

A well may expose and/or run through different types of materials (e.g., sedimentary rocks) in the ground. The materials in the ground may be grouped into related packages. For example, rocks in the ground may be grouped into packages of rocks that are bounded by chronostratigraphic surface and/or sequence stratigraphic boundaries. Rocks may be related based on their depositions by the same flow and/or sediment transport event. Because the flow and the associated sediment transport are highly correlated spatially, the spatial distribution and spatial variabilities of the sedimentary rocks that are produced by the flow and sediment transport may be predicted.

Geologic analysis and/or reservoir characterization workflow may include determining correlations between segments of different wells. A segment of a well may refer to a part of the well (e.g., a vertical part of the well). A segment of a well may include and/or be defined by one or more materials within a part of the well (e.g., sedimentary rock within a part of the well). A segment of a well may include and/or be defined by one or more materials surrounding a part of the well (e.g., sedimentary rock surrounding a part of the well). A correlation between segments of wells may refer to connection, correspondence, and/or relationship between a segment of one well to a segment of another well. A segment of one well correlated to a segment of another well may indicate that the two segments were deposited at the same time (chronostratigraphically) and/or have similar/related characteristics.

Correlation of wells may be determined lithostratigraphically. Lithostratigraphic correlation of wells may include correlation of wells based solely on their physical and/or

petrographic features. Lithostratigraphic correlation of wells may include correlation of wells that maximize cross correlations between pairs of log signals. That is, lithostratigraphic correlation may correlate wells by looking for similar patterns in the pairs of log signals. For example, segments of different wells may be linked together based on similarity of geo-patterns within the segments. However, such correlation of well segments may erroneously represent spatial distributions of rock properties and/or reservoir internal heterogeneity.

For example, FIGS. 3A-3D illustrate example segments of a well A 310 and a well B 320 drilled into ground 302. The segments of the well A 310 and the well B 320 may include division of the well A 310 and the well B 320 into related packages. The well A 310 may include segments 312, 314, 316, 318, and the well B 320 may include segments 322, 324, 326, 328. As shown in FIG. 3B, lithostratigraphic correlation of segments of wells A 310 and well B 320 may result in linking of the segment 312 to the segment 322, linking of the segment 314 to the segment 324, linking of the segment 316 to the segment 326, and the linking of the segment 318 to the segment 328. Such linking of well segments may result in a railway track style of correlation where the rock packages in the well A 310 is linked to similar rock packages in the well B 320, which may imply that the linked well segments are connected.

Such representation of spatial distributions of rock properties and/or reservoir internal heterogeneity may not be correct. For example, FIGS. 3C and 3D illustrate alternative spatial distributions of rock properties and/or reservoir internal heterogeneity between the well A 310 and the well B 320. In FIG. 3C, the well A 310 and the well B 320 may be drilled into the ground with similar properties/characteristics (e.g., delta lobes of a delta plain). However, the well A 310 and the well B 320 may be physically separated (e.g., separated by fringing parts of the delta lobes) and the segments 312, 314, 316, 318 of the well A 310 may not be connected to the segments 322, 324, 326, 328 of the well B 320. In FIG. 3D, the well A 310 and the well B 320 may be drilled into the ground with deposited layers being slanted with respect to the ground 302. The segment 312 of the well A 310 may correlate to the segment 328 of the well B 320 (rather than the segment 322). The segments 322, 324, 326 of the well B 310 may not correlate to any segments of the well A 310. The segments 314, 316, 318 of the well A 310 may or may not correlate to segments of the well B 320 below the segment 328.

An important advancement in geological studies is the development of chrono- and sequence stratigraphy. Chrono- and sequence stratigraphy recognizes that sediment rocks are deposited sequentially, one layer after the other over time. Application of chrono- and sequence stratigraphy may enable prediction of rock properties from known locations, such as at locations of wells, to unknown locations such as locations between wells and/or away from wells. In contrast with the lithostratigraphy where the grouping of rocks is based on similar rock properties, chrono- and sequence stratigraphy enables characterization of the rocks by grouping them into generically related packages. Because the rocks within the chrono- and sequence stratigraphy are generically related, within each package, the property distributions and their spatial variations are closely related to the associated depositional processes. These depositional processes are mostly spatially continuous and may be predicted. By identifying and linking the generically related packages, a chrono- and sequence stratigraphic framework may be obtained. The framework may then be used for

making predictions of related geologic properties away from the wells, as well as for building reservoir models by filling the properties in the volumes defined by the layers given by the framework.

Referring back to FIG. 1, the electronic storage 13 may be configured to include electronic storage medium that electronically stores information. The electronic storage 13 may store software algorithms, information determined by the processor 11, information received remotely, and/or other information that enables the system 10 to function properly. For example, the electronic storage 13 may store subsurface representation information, information relating to subsurface representation, information relating to simulated subsurface configuration, information relating to simulated subsurface region, information relating to simulated well, well information, information relating wells, information relating to subsurface configuration of wells, information relating to spatial arrangement of wells, information relating to similarity maps, information relating to arrangement of similarity maps, information relating to matched simulated wells, information relating to correlation between wells, and/or other information.

The processor 11 may be configured to provide information processing capabilities in the system 10. As such, the processor 11 may comprise one or more of a digital processor, an analog processor, a digital circuit designed to process information, a central processing unit, a graphics processing unit, a microcontroller, an analog circuit designed to process information, a state machine, and/or other mechanisms for electronically processing information. The processor 11 may be configured to execute one or more machine-readable instructions 100 to facilitate correlating multiple wells. The machine-readable instructions 100 may include one or more computer program components. The machine-readable instructions 100 may include one or more of a subsurface representation component 102, a well component 104, a similarity map component 106, an arrangement component 108, a correlation component 110, and/or other computer program components.

The subsurface representation component 102 may be configured to obtain subsurface representation information and/or other information. Obtaining subsurface representation information may include one or more of accessing, acquiring, analyzing, determining, examining, identifying, loading, locating, opening, receiving, retrieving, reviewing, selecting, storing, utilizing, and/or otherwise obtaining the subsurface representation information. The subsurface representation component 102 may obtain subsurface representation information from one or more locations. For example, the subsurface representation component 102 may obtain subsurface representation information from a storage location, such as the electronic storage 13, electronic storage of a device accessible via a network, and/or other locations. The subsurface representation component 102 may obtain subsurface representation information from one or more hardware components (e.g., a computing device, a component of a computing device) and/or one or more software components (e.g., software running on a computing device). Subsurface representation information may be stored within a single file or multiple files.

The subsurface representation information may define one or more subsurface representations. The subsurface representation information may define a subsurface representation by including information that describes, delineates, identifies, is associated with, quantifies, reflects, sets forth, and/or otherwise defines one or more of content, quality, attribute, feature, and/or other aspects of the sub-

surface representation. For example, the subsurface representation information may define a subsurface representation by including information that makes up the content of the subsurface representation and/or information that is used to identify/determine the content of the subsurface representation. Other types of subsurface representation information are contemplated.

A subsurface representation may refer to a computer-generated representation of a subsurface region, such as a one-dimensional, two-dimensional and/or three-dimensional model of the subsurface region. A subsurface representation may be representative of the depositional environment of wells (e.g., wells to be correlated). A subsurface representation may include geologically plausible arrangement of rock obtained from a modeling process (e.g., stratigraphic forward modeling process). A subsurface representation may provide simulated subsurface configuration at different locations within a simulated subsurface region (e.g., provide simulated well log values at locations in a three-dimensional (x-y-z) coordinate system).

A subsurface region may refer to a part of earth located beneath the surface/located underground. A subsurface region may refer to a part of earth that is not exposed at the surface of the ground. A subsurface region may be defined in a single dimension (e.g., a point, a line) or in multiple dimensions (e.g., a surface, a volume).

A subsurface representation may define simulated subsurface configuration of a simulated subsurface region. Simulated subsurface configuration may refer to subsurface configuration simulated within a subsurface representation. A simulated subsurface region may refer to a subsurface region simulated within a subsurface representation. That is, a subsurface representation may define subsurface configuration of a subsurface region simulated by one or more subsurface models. A subsurface representation may be used as and/or may be referred to as a digital analog. In some implementations, the subsurface representation information may define multiple subsurface representations. Individual ones of the subsurface representations may be used to provide separate set of correlation between the wells. That is, multiple subsurface representations may be used to find multiple scenarios of correlations between wells.

A subsurface model may refer to a computer model (e.g., program, tool, script, function, process, algorithm) that generates subsurface representations. A subsurface model may simulate subsurface configuration within a region underneath the surface (subsurface region). Subsurface configuration may refer to attribute, quality, and/or characteristics of a subsurface region. Subsurface configuration may refer to physical arrangement of materials (e.g., subsurface elements) within a subsurface region. Examples of subsurface configuration simulated by a subsurface model may include types of subsurface materials, characteristics of subsurface materials, compositions of subsurface materials, arrangements/configurations of subsurface materials, physics of subsurface materials, and/or other subsurface configuration. For instance, subsurface configuration may include and/or define types, shapes, and/or properties of materials and/or layers that form subsurface (e.g., geological, petrophysical, geophysical, stratigraphic) structures.

An example of a subsurface model is a computational stratigraphy model. A computational stratigraphy model may refer to a computer model that simulates depositional and/or stratigraphic processes on a grain size scale while honoring physics-based flow dynamics. A computational stratigraphy model may simulate rock properties, such as velocity and density, based on rock-physics equations and

assumptions. Input to a computational stratigraphy model may include information relating to a subsurface region to be simulated. For example, input to a computational stratigraphy model may include paleo basin floor topography, paleo flow and sediment inputs to the basin, and/or other information relating to the basin. In some implementations, input to a computational stratigraphy model may include one or more paleo geologic controls, such as climate changes, sea level changes, tectonics and other allocyclic controls. Output of a computational stratigraphy model may include one or more subsurface representations. A subsurface representation generated by a computational stratigraphy model may be referred to as a computational stratigraphy model representation.

A computational stratigraphy model may include a forward stratigraphic model. A forward stratigraphic model may be an event-based model, a process mimicking model, a reduced physics based model, and/or a fully physics based model (e.g., fully based on physics of flow and sediment transport). A forward stratigraphic model may simulate one or more sedimentary processes that recreate the way stratigraphic successions develop and/or are preserved. The forward stratigraphic model may be used to numerically reproduce the physical processes that eroded, transported, deposited and/or modified the sediments over variable time periods. In a forward modelling approach, data may not be used as the anchor points for facies interpolation or extrapolation. Rather, data may be used to test and validate the results of the simulation. Stratigraphic forward modelling may be an iterative approach, where input parameters have to be modified until the results are validated by actual data. Usage of other subsurface models and other subsurface representations are contemplated.

FIG. 4 illustrates an example subsurface representation **400**. The subsurface representation **400** may define simulated subsurface configuration of a simulated subsurface region. The simulated subsurface configuration may be defined within the subsurface representation **400** as a function of spatial location, such as a function of vertical spatial location (e.g., depth), lateral spatial location (e.g., x-y coordinate in map view), and/or other spatial location. For example, the subsurface representation **400** may define different types, shapes, and/or properties of materials and/or layers as a function of depth into the ground and as a function of lateral spatial location. The simulated subsurface configuration defined within the subsurface representation **400** may simulate the subsurface configuration that would be seen within a volume (e.g., well, reservoir) in the ground.

A subsurface representation may be representative of a subsurface region of interest. For example, the simulated subsurface configuration defined by a subsurface representation may be representative of the subsurface configuration of a reservoir of interest. Other subsurface regions of interest are contemplated. In some implementations, a subsurface representation may be scaled in area size and thickness to match a subsurface region of interest. For example, lateral size and/or vertical depth of a subsurface representation may be changed to be comparable to the size and thickness of a subsurface region of interest.

A simulated subsurface region of a subsurface representation may include simulated wells. For example, the simulated subsurface region of the subsurface representation **400** may include a first simulated well, a second simulated well, and/or other simulated wells. A simulated well may refer to a simulated volume, a simulated hole, and/or a simulated tunnel within the simulated subsurface region. A simulated well may refer to a portion of the subsurface representation/

simulated subsurface region that includes, runs through, and/or exposes different types of simulated layers. A simulated well may be characterized by the simulated layers that are included within and/or surround the simulated well. A simulated well may extend along one or more directions. For example, a simulated well may include a simulated vertical well, a simulated horizontal well, a simulated deviated well, and/or other type of simulated well.

Simulated subsurface configuration of a simulated subsurface region may define simulated correlation between simulated wells within the simulated subsurface region. Simulated correlation between simulated wells may refer to correlation simulated between simulated wells within a subsurface representation. The subsurface configuration between wells in a subsurface region simulated within a subsurface representation may define the correlation between the wells.

For example, the simulated subsurface configuration of the simulated subsurface region may describe, identify, quantify, reflect, and/or set forth how different simulated wells within the simulated subsurface region are correlated. For example, the subsurface representation **400** (shown in FIG. 4) may include multiple simulated wells in different locations within the simulated subsurface region. The simulated subsurface configuration of the subsurface representation **400** may define how the different wells are correlated based on the locations of the wells within the subsurface representation **400** and the connectivity of rocks between the different locations. For instance, the subsurface representation **400** may include a first simulated well and a second simulated, and the simulated subsurface configuration between the two simulated wells may define simulated correlation between the first simulated well and the second simulated well.

In some implementations, a subsurface representation may include a computational stratigraphy model representation, and the correlation between the wells may include chrono-sequence stratigraphic correlation. The correlation of wells within the computational stratigraphy model representation may include packages of rocks linked together in a geologic way. Because the computational stratigraphy model representation is built sequentially, layer by layer, the chrono- and sequence stratigraphic correlations between any simulated wells in the subsurface representation may be given by the layers of the subsurface representation. The layers of the subsurface representation between the simulated wells may determine the connectivity and/or other linkage characteristics of the simulated wells.

The well component **104** may be configured to obtain well information and/or other information. Obtaining well information may include one or more of accessing, acquiring, analyzing, determining, examining, identifying, loading, locating, opening, receiving, retrieving, reviewing, selecting, storing, utilizing, and/or otherwise obtaining the well information. The well component **104** may obtain well information from one or more locations. For example, the well component **104** may obtain well information from a storage location, such as the electronic storage **13**, electronic storage of a device accessible via a network, and/or other locations. The well component **104** may obtain well information from one or more hardware components (e.g., a computing device, a component of a computing device) and/or one or more software components (e.g., software running on a computing device). Well information may be stored within a single file or multiple files.

The well information may define subsurface configuration of wells and spatial arrangement of the wells. For example,

the well information may define subsurface configuration and spatial arrangement of a first well, a second well, and/or other wells. The subsurface configuration of a well may be defined as a function of spatial location (e.g., vertical spatial location, lateral spatial location). Subsurface configuration of a well may refer to attribute, quality, and/or characteristics of the well. Subsurface configuration of a well may refer to physical arrangement of materials (e.g., subsurface elements) within the well. Spatial arrangement of wells may refer to how the wells are physically arranged with respect to one another. Spatial arrangement of wells may include relative positions of the wells. The relative positions of the wells may include relative lateral positions (e.g., lateral direction and distance between wells), relative vertical positions (e.g., vertical direction and distance between wells), relative orientation of wells, and/or other relative positions.

The well information may define subsurface configuration of wells and spatial arrangement of the wells by including information that describes, delineates, identifies, is associated with, quantifies, reflects, sets forth, and/or otherwise defines one or more of content, quality, attribute, feature, and/or other aspects of the surface configuration of the wells and spatial arrangement of the wells. For example, the well information may define subsurface configuration of wells by including information that makes up the content of the wells and/or information that is used to identify/determine the content of the wells. For instance, the well information may include one or more well logs, information determined/extracted from one or more well logs, information determined/extracted from one or more well cores, and/or other information. For example, the well information may provide information on one or more properties of the wells, such as rock types, layers, grain sizes, porosity, and/or permeability. The well information may define spatial arrangement of wells by including information that sets forth the relative positions of the wells and/or information that is used to identify/determine the relative positions of the wells.

FIG. 5 illustrates an example spatial arrangement of wells. In FIG. 5, a well **502** and a well **504** may be separated by a distance **D1**, the well **502** and a well **506** may be separated by a distance **D2**, and the well **504** and the well **506** may be separated by a distance **D3**. While the spatial arrangement of wells shown in FIG. 5 shows lateral distances between the wells, this is merely as an example and is not meant to be limiting. Relative positions of wells may include difference in lateral locations, difference in vertical locations, and/or difference in other locations of the wells.

The similarity map component **106** may be configured to generate similarity maps for the wells. The similarity map component **106** may be configured to generate one or more similarity maps for individual ones of the wells. For example, the similarity maps may include a first similarity map for the first well, a second similarity map for the second well, and/or other similarity maps for other wells. A similarity map may characterize extent of similarity between the corresponding well and different locations within the simulated subsurface region. For example, a similarity map may show the quantity and/or quality of matching between the wells and the simulated wells within the simulated surface region. The extent of similarity between the corresponding well and different locations within the simulated subsurface region may be given by one or more similarity measures/scores of the similarity map. The similarity measures/scores may enable comparison of well-similarity between different locations within the simulated subsurface region. For example, the similarity measures/scores may enable comparison of whether one simulated well positioned at one

location within the simulated subsurface region is a better or worse match to a well than another simulated well positioned at another location within the simulated subsurface region.

The similarity maps may be generated based on comparison of the subsurface configuration of the wells with the simulated subsurface configuration of the simulated subsurface region, and/or other information. For example, lithological comparison may be performed between the subsurface configuration of the wells with the simulated subsurface configuration of the simulated subsurface region to determine to what extent the simulated subsurface configuration a simulated well matches the subsurface configuration of a well.

In some implementations, the simulated subsurface configuration of the simulated subsurface region may be transformed so that the transformed simulated subsurface configuration is comparable to the subsurface configuration of the wells, or vice versa. For example, if the digital analog contains simulated grain size logs for different locations within the simulated subsurface region and the well information includes neutron density logs of wells, the simulated grain size logs of the digital analog may be transformed into neutron density logs by applying one or more transformation functions, thereby making the simulated subsurface configuration of the simulated wells comparable to the subsurface configuration of the wells.

The extent of similarity between a well and a simulated well may be determined for the entire length of the well and/or for different segments of the well. For example, segments/packages of well along the length of the well may be compared to simulated segments/packages of simulated well along the length of the simulated well to determine similarity between the segments/packages of well and the simulated segments/packages of simulated well. The similarity between the segments/packages may be combined (e.g., averaged, weighted) to provide a similarity measure/score for the simulated well at a particular lateral location. The similarity measures/scores may be generated for different lateral (x-y) location within the simulated surface region to generate a two-dimensional similarity map. As another example, multiple similarity measures/scores may be provided for a simulated well at a particular lateral location, with the different similarity measures/scores reflecting the extent of similarity for different vertical portions (e.g., different vertical segment/package, different length of well) of the well. The similarity measures/scores may be generated for different lateral and vertical locations within the simulated surface region to generate a three-dimensional similarity map.

For example, for a location within the simulated region/subsurface representation, the simulated subsurface configuration of a simulated well, such as contained in a simulated well log, may be obtained. The subsurface configuration of a well, such as contained in a well log, may be compared to the simulated subsurface configuration of the simulated well using one or more pattern recognition techniques, pattern matching techniques, lithostratigraphic analysis techniques, and/or other comparison techniques. The comparison may result in mapping of a vertical portion in the well log to a corresponding vertical portion in the simulated well log, and a similarity measure/score that indicates the quality of matching between the two vertical portions (e.g., high score for high matching and low score for low matching, or vice versa).

In some implementations, user may select one or more parameters used to perform comparison between subsurface

configuration of a well and simulated subsurface configuration of a simulated well. For example, user may select which comparison techniques may be used to perform the comparison, which characteristics of the subsurface configuration are factored in the comparison, the number of segments into which a well is divided for comparison, how the subsurface configuration are sampled for comparison, how different characteristics of the subsurface configuration are weighed in the comparison (e.g., equal or different weighing of different characteristics), and/or the lateral and/or vertical size of the wells compared at a time, the length of the wells compared for a lateral location. Other user controls are contemplated.

In some implementations, vertical offsets in spatial locations may be taken into account for generation of similarity measure/score and/or similarity maps. For example, a well log may be compared to more than one simulated well log sub-sequence from the digital analog at a given lateral (x-y) location. The geometry of a sub-sequence may be defined by a top point (x, y, z-top) and/or a bottom point (x, y, z-bottom) within the digital analog. One or both of the top point and the bottom point may be varied to provide similarity measure/score for different vertical locations/portions within the simulated subsurface region/subsurface representation. As another example, the top point or the bottom point and the thickness of the sub-sequence may be varied to provide similarity measure/score for different vertical locations/portions within the simulated subsurface region/subsurface representation.

The comparison of wells to different locations within a simulated subsurface region/subsurface representation may begin at the top of the simulated subsurface region/subsurface representation, at the bottom of the simulated subsurface region/subsurface representation, and/or somewhere in the middle of the simulated subsurface region/subsurface representation. That is, a simulated well may extend from the top of the simulated subsurface region/subsurface representation, extend from the bottom of the simulated subsurface region/subsurface representation, or contained within middle of the simulated subsurface region/subsurface representation.

In some implementations, different similarity measure/score and/or different similarity maps may be generated for different intervals of wells. For example, rather than having a single similarity measure/score or a single similarity map to provide comparison for entire length of a well and different locations within the simulated subsurface region/subsurface representation, separate similarity measures/scores and/or a separate similarity maps may be generated for different vertical intervals (slices) of the well and the simulated subsurface region/subsurface representation. In some implementations, the sizes of wells/well portions and simulated wells/simulated well portions that are compared may be different. For example, subsurface configuration of a 10-meter portion of a well may be compared to simulated subsurface configuration of an 8-meter portion and/or a 12-meter portion of a simulated well. Other generation of similarity measure/score and/or similarity maps are contemplated.

In some implementations, a similarity map may be generated and/or stored as a heat map. The extent of similarity may be given within the heat map based on one or more visual characteristics (e.g., intensity, color) of the pixels within the heat map. In some implementations, a similarity map may be generated and/or stored as a matrix. The matrix may include cells for different positions within the simulated

subsurface region, and the similarity measures/scores for the corresponding positions may be stored as one or more values within the cells.

FIG. 6A illustrates example similarity maps **602**, **604**, **606**. Individual ones of the similarity maps **602**, **604**, **606** may characterize extent of similarity between the corresponding wells and different locations within the simulated subsurface region/subsurface representation. For example, the similarity map **602** may characterize extent of similarity between the well **502** and different locations within the simulated subsurface region/subsurface representation, the similarity map **604** may characterize extent of similarity between the well **504** and different locations within the simulated subsurface region/subsurface representation, and the similarity map **606** may characterize extent of similarity between the well **506** and different locations within the simulated subsurface region/subsurface representation

In some implementations, generation of the similarity maps may include determination of preferred well-matching locations for portions of the similarity maps. The preferred well-matching locations may be determined based on the extent of similarity between individual ones of the wells and different locations within the portions of the similarity maps, and/or other information. For example, the preferred well-matching locations may be determined based on similarity measures/scores for different locations within portions of the similarity maps.

A preferred well-matching location for a portion of a similarity map may refer to a location at which a matched simulated well may be located for the portion of the similarity map. The portion of the similarity map may include a two-dimensional portion (area) or a three-dimensional portion (volume). Preferred well-matching locations may allow for variance from the spatial arrangement of the wells. For example, for a location in a similarity map, simulated wells within a corresponding portion of the similarity map may be analyzed to find a preferred (e.g., best) matching simulated well within the portion. For the location in the similarity map, the preferred matching simulated well may be selected as the simulated well to be matched with the well.

FIG. 6B illustrates example preferred well-matching locations for portions of similarity maps. A preferred well-matching similarity map **612** may show preferred well-matching locations for different portions of the similarity map **602**. A preferred well-matching similarity map **614** may show preferred well-matching locations for different portions of the similarity map **604**. A preferred well-matching similarity map **616** may show preferred well-matching locations for different portions of the similarity map **606**.

In some implementations, the portions of the similarity maps may include regions of the similarity maps within boundaries for corresponding locations. The boundaries for the corresponding locations may be defined by one or more symmetrical shapes and/or one or more asymmetrical shapes. The boundaries may include the corresponding locations. For example, the boundaries for corresponding locations may define a shape, such as a circular shape, polygonal shape, and/or other shape. For instance, the boundaries for corresponding locations may define circles. The circles may include the corresponding location, such as at the center of the circles. The circles may be defined by a radius (snap radius) around the corresponding locations.

For example, referring to FIG. 6B, for a location **652**, the portion of the similarity map **614** may include a region within a boundary **654**. The boundary **654** may be defined by a circle including the location **652**. The boundary **652** may be centered at the location **652**, and be defined by a radius

R around the location **652**. The radius R may be a lateral distance (between two coordinates (x1, y1) and (x2, y2)) which is considered a tolerable error in the lateral spatial locations of matched simulated wells. Other parameters may be used to specify tolerance in position error. While the boundary **654** shown in FIG. 6B shows a two-dimensional boundary, this is merely as an example and is not meant to be limiting. The boundary may be defined by lateral dimensions, vertical dimension, and/or other dimensions. The size of the boundary may correspond to the amount of tolerable error in matching simulated wells to wells. A larger boundary may generally enable well matching with simulated wells having greater similarity (e.g., higher similarity measure/score) while introducing greater mismatch between the spatial arrangement of the matched simulated wells and the spatial arrangement of the wells. For example, a snap radius of R may introduce up to 2R error in mismatch between locations of simulated wells and locations of wells.

Simulated wells within the boundary **654** may be compared with a corresponding well (the well **504**) to identify a preferred simulated well within the boundary **654**. The preferred simulated well may be identified based on the similarity measures/scores for the simulated wells within the boundary and/or other information. For example, a simulated well located at a location **656** may be identified as the preferred simulated well within the boundary **654** based on the simulated well located at the location **656** being the best match (e.g., highest similarity measure/score) for the well **504**. The location **656** may be associated with the location **652** as the preferred well-matching location. When the simulated well at the location **652** is considered for matching with a well, the simulated well at the location **656** may actually be used.

The similarity maps may be scanned to find preferred well-matching locations for different locations within the similarity maps. A map including information on the preferred well-matching locations may be referred to as a preferred well-matching similarity map. The preferred well-matching similarity map may relate individual locations in the map to the corresponding preferred well-matching locations. For example, a preferred well-matching similarity map may include a list of spatial locations in the digital analog and a reference to the preferred well-matching locations for the spatial locations.

In some implementations, a preferred well-matching similarity map may be stored as a matrix. The matrix may include cells for different positions within the simulated subsurface region, and the preferred well-matching locations for corresponding positions and the similarity measures/scores for the preferred well-matching locations may be stored as one or more values within the cells. For example, for the preferred well-matching similarity map **614**, individual cells may store the preferred well-matching locations within the radius of the circular boundary and the similarity measure/score of the simulated wells at the preferred well-matching locations. For instance, for the location **652**, a cell may store the location **656** and the similarity measure/score of the simulated well at the location **656**.

Same or different boundaries may be used for different wells. For example, boundaries with same or different radius may be used to determine preferred well-matching locations within the similarity maps **602**, **604**, **606**. The boundaries may be symmetrical or asymmetrical. For example, a vertical snap radius and a lateral snap radius to define a three-dimensional boundary may be same or different.

The arrangement component **108** may be configured to arrange the similarity maps based on the spatial arrangement

of the wells and/or other information. Arranging similarity maps may include arranging the similarity maps and/or arranging corresponding preferred well-matching similarity maps. Arranging the similarity maps may include spatially organizing, positioning, and/or moving the similarity maps. Arranging the similarity maps may include shifting the similarity maps. For example, the similarity maps may be shifted laterally and/or vertically. The similarity maps may be arranged in accordance with the spatial arrangement of the well. The similarity maps may be arranged to match the spatial arrangement of the well.

In some implementations, the arrangement of the similarity maps may include the similarity maps displaced from a rotation center location to match displacement of corresponding wells from the rotation center location. A rotation center location may refer to a location about which the well and/or the similarity maps may be rotated. The rotation center location may be chosen arbitrarily with respect to the wells and/or the similarity maps. The rotation center location may be chosen based on the wells, such as to be located at a well location or at the center of the wells. Other rotation center locations are contemplated.

The amount by which a similarity map is displaced from the rotation center location may match (e.g., be equal to, be equivalent to) the amount by which the corresponding well is displaced from the rotation center location. The direction in which a similarity map is displaced from the rotation center location may match (e.g., be in the same direction as, be in the opposite direction of) the direction in which the corresponding well is displaced from the rotation center location. For example, a well may be located five units to the right of the rotation center location. The corresponding similarity map may be shifted to the right or left of the rotation center location by five units.

The similarity maps may be arranged such that the similarity maps/preferred well-matching similarity maps overlap with each other within an overlap area. Locations within the overlap area of the arranged similarity maps/arranged preferred well-matching similarity maps may correspond to groupings of matched simulated wells. Use of the preferred well-matching similarity maps may enable matching of wells with simulated wells at the preferred well-matching locations (e.g., find a set of “locally best” simulated wells to match to the wells).

FIG. 7A illustrates an example arrangement of similarity maps. A rotation center location 702 may be chosen as shown in FIG. 7A. The well 502 may be located to the left of the rotation center location 702. The preferred well-matching similarity map 612 (corresponding to the well 502) may be shifted to the left of the rotation center location 702 by the same/equivalent amount. The well 504 may be located above the rotation center location 702. The preferred well-matching similarity map 614 (corresponding to the well 504) may be shifted above the rotation center location 702 by the same/equivalent amount. The well 506 may be located above and to the right of the rotation center location 702. The preferred well-matching similarity map 616 (corresponding to the well 506) may be shifted above and to the left of the rotation center location 702 by the same/equivalent amount. The arrangement of the preferred well-matching similarity maps 612, 614, 616 may result in the preferred well-matching similarity maps 612, 614, 616 overlapping with each other within an overlap area 704.

In some implementations, the wells and the similarity maps may be rotated about the rotation center location. Rotation of the wells and the similarity maps about the rotation center location may change the arrangement of the

similarity maps and the overlap area covered by the similarity maps. Rotation of the wells and the similarity maps about the rotation center location may not change the spatial arrangement (e.g., relative positions) of the wells. Changes to the overlap area may result in changes to the groupings of matched simulated wells corresponding to the locations within the overlap area. The wells and the similarity maps may be rotated about the rotation center location in a circle (full circle—360 degrees, partial circle—less than 360 degrees) to provide different groupings of matched simulated wells. Other transformations (e.g., rescaling, warping) are contemplated.

FIG. 7B illustrates an example arrangement of similarity maps. In FIG. 7B, the wells 502, 504, 506 may be rotated about the rotation center location 702. Compared to FIG. 7A, the wells 502, 504, 506 may be rotated to the right. The preferred well-matching similarity maps 612, 614, 616 may be rotated to the right by the same/equivalent amount to match the arrangement of the wells 502, 504, 506 with respect to the rotation center location 702. The rotation of the preferred well-matching similarity maps 612, 614, 616 may result in the preferred well-matching similarity maps 612, 614, 616 overlapping with each other within an overlap area 706. The overlap area 706 may be different from the overlap area 704. Change to the overlap area may result in a point of the preferred well-matching similarity map 612 within the overlap area 706 being associated with different points of the preferred well-matching similarity map 614, 616 than within the overlap area 704.

In some implementations, the wells and the similarity maps may be flipped about a line. For example, the spatial arrangement of the wells may be changed by flipping locations of the wells about a line. Such changes to the spatial arrangement of the wells may result in changes to the arrangement of the similarity maps, which may result in changes to the overlap area covered by the similarity maps.

FIG. 7C illustrates an example arrangement of similarity maps. In FIG. 7C, the wells 502, 504, 506 may be flipped about a vertical line running through the rotation center location 702. Compared to FIG. 7A, the wells 502, 504, 506 may be flipped horizontally. The preferred well-matching similarity maps 612, 614, 616 may be flipped horizontally to match the arrangement of the wells 502, 504, 506 with respect to the rotation center location 702. The horizontal flipping of the preferred well-matching similarity maps 612, 614, 616 may result in the preferred well-matching similarity maps 612, 614, 616 overlapping with each other within an overlap area 708. The overlap area 708 may be different from the overlap area 704. Change to the overlap area may result in a point of the preferred well-matching similarity map 612 within the overlap area 708 being associated with different points of the preferred well-matching similarity map 614, 616 than within the overlap area 704.

Arranging the similarity maps to find simulated wells matched to the well (e.g., real wells) may reduce the complexity of the search for the matched simulated wells. Increase in number of the wells may only linearly (rather than exponentially) increase the computational complexity of the search to match simulated wells to wells (e.g., real wells to be correlated).

In some implementations, the similarity maps may be represented as matrices, with individual cells in the matrices corresponding to positions in the subsurface representation. The similarity maps may be arranged by arranging the matrices, and individual overlapping of cells within the matrices may correspond to individual groupings of matched simulated wells. To arrange the matrices, shift vectors

between well locations and the rotation center location may be calculated. Shift vector may point from the rotation center location to the well locations, or vice versa. The shift vector may be added to individual cells in the matrices (e.g., preferred well-matching similarity map matrices) to obtain shifted matrices (e.g., shifted preferred well-matching similarity map matrices). Similarly, rotation transformation may be applied to the matrices to obtain rotated matrices. The overlap of the shifted/rotated matrices may represent groupings of matched simulated wells.

Locations within the overlap area of the arranged (e.g., shifted, rotated, flipped) similarity maps/arranged preferred well-matching similarity maps may correspond to groupings of matched simulated wells. Individual groupings of matched simulated wells may include a matched simulated well for individual ones of the wells. That is, individual locations within the overlap area may provide individual groupings of simulated wells that honor the spatial arrangement of the wells. Individual locations within the overlap area may represent a potential grouping of matched simulated wells.

A matched simulated well within the simulated subsurface region/subsurface representation may refer to a simulated well that has been matched/mapped to a well. Matched simulated wells may be identified within the simulated subsurface region/subsurface representation to determine correlation between the corresponding wells. A grouping of matched simulated well may refer to a set of matched simulated wells within the simulated subsurface region/subsurface representation. Individual groupings of matched simulated wells may include a matched simulated well for individual ones of the wells. For example, for a triplet of wells, a grouping of matched simulated wells may include a first simulated well matched to a first well, a second simulated well matched to a second well, and a third simulated well matched to a third well.

FIGS. 8A, 8B, and 8C illustrate an example grouping of matched simulated wells. FIG. 8A may illustrate a location 802 within the overlap area 704 of the preferred well-matching similarity maps 612, 614, 616. The location 804 may correspond to a grouping of matched simulated wells. As shown in FIG. 8B, the location 804 may correspond to a simulated well 812 (located within the preferred well-matching similarity map 612), a simulated well 814 (located within the preferred well-matching similarity map 612), and a simulated well 816 (located within the preferred well-matching similarity map 612). Selection of the location 802 to match simulated wells to the wells may include the simulated well 812 being matched to the well 502, the simulated well 814 being matched to the well 504, and the simulated well 816 being matched to the well 506.

Based on the arrangement of the similarity maps, the simulated wells 812, 814, 816 may honor the spatial arrangement of the wells 502, 504, 506. For example, FIG. 8C shows a combined similarity map 800. The combined similarity map 800 may include the preferred well-matching similarity maps 612, 614, 616 stacked on top of each other. The combined similarity map 800 may show the relative positions of the simulated wells 812, 814, 816 within the corresponding preferred well-matching similarity maps 612, 614, 616. The simulated well 812 and the simulated well 814 may be separated by a distance D1 (or within distance tolerance of D1), the simulated well 812 and the simulated well 816 may be separated by a distance D2 (or within distance tolerance of D2), and the simulated well 814 and the simulated well 816 may be separated by a distance D3 (or within distance tolerance of D3).

Thus, the simulated distances between the simulated wells 812, 814, 816 may match the distances between the wells 502, 504, 506. In some implementations, a simulated distance may match the corresponding distance based on the simulated distance being within one or more tolerance distances of the corresponding distance. The simulated relative positions of the simulated wells 812, 814, 816 may match the relative positions of the wells 502, 504, 506. In some implementations, simulated relative positions may match the corresponding relative positions based on the simulated relative positions being within one or more tolerance distances of the corresponding relative positions.

In some implementations, multiple groupings of matched simulated wells may be identified within a simulated subsurface region/subsurface representation by selecting multiple locations within the overlap area. The different groupings of matched simulated wells may include one or more of the simulated wells being located at different locations within the simulated subsurface region/subsurface representation. Individual grouping of matched simulated wells may provide a scenario of correlation between the wells. Thus, multiple scenarios of correlations between wells may be determined from a single simulated subsurface region/subsurface representation by identifying multiple groupings of matched simulated wells.

In some implementations, matching quality of individual grouping of matched simulated wells may be determined. The matching quality of individual grouping of matched simulated wells may be determined based on extent of matching of the matched simulated wells with corresponding wells, extent of matching of simulated spatial arrangement of the matched simulated wells with the spatial arrangement of the wells, and/or other information. For example, the match quality of a grouping of matched simulated wells to wells may be determined based on the extent to which the simulated subsurface configuration of the matched simulated wells matches the subsurface configuration of the wells. The match quality of a grouping of matched simulated wells to wells may be determined based on the extent to which the simulated spatial arrangement of the matched simulated wells matches the spatial arrangement of the wells. The matching quality of individual grouping of matched simulated wells may be used to quantify the likelihood of the well correlation provided by the individual grouping of matched simulated wells. That is, the matching quality of a grouping of matched simulated well may indicate the likelihood that the well correlation provided (e.g., predicted, estimated) by the grouping of matched simulated well may match actual and/or realistic correlation between the wells in the real world.

The correlation component 110 may be configured to determine correlation between the wells based on the simulated correlation between the matched simulated wells and/or other information. The simulated subsurface configuration between the matched simulated wells in the simulated subsurface region/subsurface representation may define simulated correlation between the matched simulated wells, and these simulated correlation may be used as and/or used to determine the correlation between the corresponding wells. That is, the simulated subsurface region/subsurface representation including simulated wells may define simulated correlation between the simulated wells, and the simulated correlation between the simulated wells in the simulated subsurface region/subsurface representation may be used to determine correlation between wells in the real world.

In some implementations, a subsurface representation may include a computational stratigraphy model representation, and the correlation between the wells may include chrono-sequence stratigraphic correlation. That is, the computational stratigraphy model representation may provide simulated chrono-sequence stratigraphic correlation between simulated wells within the representation, and the matching of the real wells to the simulated wells may be used to provide the simulated chrono-sequence stratigraphic correlation between simulated wells as the chrono-sequence stratigraphic correlation between the wells in the real world.

For example, a simulated well A' in a simulated subsurface region/subsurface representation may be matched to a well A, and a simulated well B' in a simulated subsurface region/subsurface representation may be matched to a well B (based on similarity maps for wells A and B and spatial arrangement of the wells A and B). The simulated subsurface configuration between the simulated well A' and the simulated well B' in the simulated subsurface region/subsurface representation may define simulated correlation between the simulated well A' and the simulated well B'. The correlation between the well A and the well B may be determined based on the simulated correlation between the simulated well A' and the simulated well B', and/or other information. The correlation between the well A and the well B (between segments of wells A and B) may be equivalent to the simulated correlation between the simulated well A' and the simulated well B' (between segments of simulated wells A' and B'), as defined within the simulated subsurface region/subsurface representation.

Thus, a direct and automated chronostratigraphic correlation between wells may be determined using subsurface representations. Because a subsurface representation (e.g., from a forward model, computational stratigraphy model) contains the chrono- and sequence stratigraphic correlations between pairs of any simulated wells, matching (mapping) of real wells to simulated wells enables simulated correlations between the simulated wells to be used as and/or to determine correlations of real wells.

By matching a real well to a simulated well, every layer of the deposit in the real well is mapped to a layer in the simulated well, and the connectivity of the layers between the real well is determined using the simulated connectivity of the layers between the simulated wells. Using simulated correlation between simulated wells in the subsurface representation as correlation between real wells may result in multiple well correlation to be automatically tied. Lithostratigraphic correlation of wells, on the other hand, may result in mismatch in correlation. For example, referring to FIG. 5, lithostratigraphy correlation may be used to determine correlation between the well 502 and the well 504 and determine correlation between the well 504 and the well 506. Such correlation determined between the wells 502, 504, 506 may result in mismatch in correlation (devil's stairs) between the well 502 and the well 506. The direct and automated chronostratigraphic correlation between wells as described herein may result in correlation between multiple wells that are automatically tied. For example, referring to FIG. 8C, the grouping of matched simulated wells 812, 814, 816 may result in correlation between the corresponding wells 502, 504, 506 that are automatically tied.

In some implementations, multiple scenarios of correlation between the wells may be provided based on identification of multiple groupings of matched simulated well within the stimulated surface region and/or other information. Individual grouping of matched simulated wells may provide a scenario of correlation between the wells. For

example, referring to FIG. 8A, multiple locations within the overlap area 704 may be used to provide multiple groupings of matched simulated wells, and the separate groupings of matched simulated wells may provide separate scenarios of correlation between the wells. Thus, multiple scenarios of correlation between the wells may be provided using a single subsurface representation.

In some implementations, separate sets of correlation between the wells may be provided based on the subsurface representation information defining multiple subsurface representations and/or other information. A set of correlation between the wells may include one or more correlation between the wells. Individual ones of the subsurface representations may be used to provide separate set of correlation between the wells. That is, separate subsurface representations may be used to provide separate sets of correlation between the wells. Different subsurface representations may provide simulation of different subsurface regions, different simulated subsurface configuration, and/or different simulated correlation between simulated wells.

In some implementations, the matching qualities of different subsurface representations may be determined based on extent of matching of the matched simulated wells with corresponding wells, extent of matching of simulated spatial arrangement of the matched simulated wells with the spatial arrangement of the wells, and/or other information. The matching quality of individual subsurface representation may be used to quantify the likelihood of the well correlation provided by the individual subsurface representation. That is, the matching quality of a subsurface representation may indicate the likelihood that the well correlation provided (e.g., predicted, estimated) by the subsurface representation may match actual and/or realistic correlation between the wells in the real world.

Implementations of the disclosure may be made in hardware, firmware, software, or any suitable combination thereof. Aspects of the disclosure may be implemented as instructions stored on a machine-readable medium, which may be read and executed by one or more processors. A machine-readable medium may include any mechanism for storing or transmitting information in a form readable by a machine (e.g., a computing device). For example, a tangible computer-readable storage medium may include read-only memory, random access memory, magnetic disk storage media, optical storage media, flash memory devices, and others, and a machine-readable transmission media may include forms of propagated signals, such as carrier waves, infrared signals, digital signals, and others. Firmware, software, routines, or instructions may be described herein in terms of specific exemplary aspects and implementations of the disclosure, and performing certain actions.

In some implementations, some or all of the functionalities attributed herein to the system 10 may be provided by external resources not included in the system 10. External resources may include hosts/sources of information, computing, and/or processing and/or other providers of information, computing, and/or processing outside of the system 10.

Although the processor 11 and the electronic storage 13 are shown to be connected to the interface 12 in FIG. 1, any communication medium may be used to facilitate interaction between any components of the system 10. One or more components of the system 10 may communicate with each other through hard-wired communication, wireless communication, or both. For example, one or more components of the system 10 may communicate with each other through a network. For example, the processor 11 may wirelessly

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communicate with the electronic storage **13**. By way of non-limiting example, wireless communication may include one or more of radio communication, Bluetooth communication, Wi-Fi communication, cellular communication, infrared communication, or other wireless communication. Other types of communications are contemplated by the present disclosure.

Although the processor **11** is shown in FIG. **1** as a single entity, this is for illustrative purposes only. In some implementations, the processor **11** may comprise a plurality of processing units. These processing units may be physically located within the same device, or the processor **11** may represent processing functionality of a plurality of devices operating in coordination. The processor **11** may be separate from and/or be part of one or more components of the system **10**. The processor **11** may be configured to execute one or more components by software; hardware; firmware; some combination of software, hardware, and/or firmware; and/or other mechanisms for configuring processing capabilities on the processor **11**.

It should be appreciated that although computer program components are illustrated in FIG. **1** as being co-located within a single processing unit, one or more of computer program components may be located remotely from the other computer program components. While computer program components are described as performing or being configured to perform operations, computer program components may comprise instructions which may program processor **11** and/or system **10** to perform the operation.

While computer program components are described herein as being implemented via processor **11** through machine-readable instructions **100**, this is merely for ease of reference and is not meant to be limiting. In some implementations, one or more functions of computer program components described herein may be implemented via hardware (e.g., dedicated chip, field-programmable gate array) rather than software. One or more functions of computer program components described herein may be software-implemented, hardware-implemented, or software and hardware-implemented.

The description of the functionality provided by the different computer program components described herein is for illustrative purposes, and is not intended to be limiting, as any of computer program components may provide more or less functionality than is described. For example, one or more of computer program components may be eliminated, and some or all of its functionality may be provided by other computer program components. As another example, processor **11** may be configured to execute one or more additional computer program components that may perform some or all of the functionality attributed to one or more of computer program components described herein.

The electronic storage media of the electronic storage **13** may be provided integrally (i.e., substantially non-removable) with one or more components of the system **10** and/or as removable storage that is connectable to one or more components of the system **10** via, for example, a port (e.g., a USB port, a Firewire port, etc.) or a drive (e.g., a disk drive, etc.). The electronic storage **13** may include one or more of optically readable storage media (e.g., optical disks, etc.), magnetically readable storage media (e.g., magnetic tape, magnetic hard drive, floppy drive, etc.), electrical charge-based storage media (e.g., EPROM, EEPROM, RAM, etc.), solid-state storage media (e.g., flash drive, etc.), and/or other electronically readable storage media. The electronic storage **13** may be a separate component within the system **10**, or the electronic storage **13** may be provided

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integrally with one or more other components of the system **10** (e.g., the processor **11**). Although the electronic storage **13** is shown in FIG. **1** as a single entity, this is for illustrative purposes only. In some implementations, the electronic storage **13** may comprise a plurality of storage units. These storage units may be physically located within the same device, or the electronic storage **13** may represent storage functionality of a plurality of devices operating in coordination.

FIG. **2** illustrates method **200** for correlating multiple wells. The operations of method **200** presented below are intended to be illustrative. In some implementations, method **200** may be accomplished with one or more additional operations not described, and/or without one or more of the operations discussed. In some implementations, two or more of the operations may occur substantially simultaneously.

In some implementations, method **200** may be implemented in one or more processing devices (e.g., a digital processor, an analog processor, a digital circuit designed to process information, a central processing unit, a graphics processing unit, a microcontroller, an analog circuit designed to process information, a state machine, and/or other mechanisms for electronically processing information). The one or more processing devices may include one or more devices executing some or all of the operations of method **200** in response to instructions stored electronically on one or more electronic storage media. The one or more processing devices may include one or more devices configured through hardware, firmware, and/or software to be specifically designed for execution of one or more of the operations of method **200**.

Referring to FIG. **2** and method **200**, at operation **202**, subsurface representation information may be obtained. The subsurface representation information may define one or more subsurface representations. A subsurface representation may define simulated subsurface configuration of a simulated subsurface region including simulated wells. The simulated subsurface configuration of the simulated subsurface region may define simulated correlation between the simulated wells. In some implementation, operation **202** may be performed by a processor component the same as or similar to the subsurface representation component **102** (Shown in FIG. **1** and described herein).

At operation **204**, well information may be obtained. The well information may define subsurface configuration of wells and spatial arrangement of the wells. In some implementation, operation **204** may be performed by a processor component the same as or similar to the well component **104** (Shown in FIG. **1** and described herein).

At operation **206**, similarity maps for the wells may be generated based on comparison of the subsurface configuration of the wells with the simulated subsurface configuration of the simulated subsurface region and/or other information. Individual similarity maps may characterize extent of similarity between individual ones of the wells and different locations within the simulated subsurface region. In some implementation, operation **206** may be performed by a processor component the same as or similar to the similarity map component **106** (Shown in FIG. **1** and described herein).

At operation **208**, the similarity maps may be arranged based on the spatial arrangement of the wells and/or other information. The similarity maps may be arranged such that the similarity maps overlap with each other within an overlap area. Locations within the overlap area may correspond to groupings of matched simulated wells. Individual groupings may include a matched simulated well for indi-

vidual ones of the wells. In some implementation, operation 208 may be performed by a processor component the same as or similar to the arrangement component 108 (Shown in FIG. 1 and described herein).

At operation 210, correlation between the wells may be determined based on the simulated correlation between the matched simulated wells and/or other information. In some implementation, operation 210 may be performed by a processor component the same as or similar to the correlation component 110 (Shown in FIG. 1 and described herein).

Although the system(s) and/or method(s) of this disclosure have been described in detail for the purpose of illustration based on what is currently considered to be the most practical and preferred implementations, it is to be understood that such detail is solely for that purpose and that the disclosure is not limited to the disclosed implementations, but, on the contrary, is intended to cover modifications and equivalent arrangements that are within the spirit and scope of the appended claims. For example, it is to be understood that the present disclosure contemplates that, to the extent possible, one or more features of any implementation can be combined with one or more features of any other implementation.

What is claimed is:

1. A system for correlating multiple wells, the system comprising:

one or more physical processors configured by machine-readable instructions to:

obtain subsurface representation information defining a subsurface representation, the subsurface representation defining simulated subsurface configuration of a simulated subsurface region including simulated wells, the simulated subsurface configuration of the simulated subsurface region defining simulated correlation between the simulated wells;

obtain well information, the well information defining subsurface configuration of wells and spatial arrangement of the wells;

generate similarity maps for the wells based on comparison of the subsurface configuration of the wells with the simulated subsurface configuration of the simulated subsurface region, individual similarity maps characterizing extent of similarity between individual ones of the wells and different locations within the simulated subsurface region, wherein the individual similarity maps characterizing the extent of similarity between the individual ones of the wells and the different locations within the simulated subsurface region includes the individual similarity maps including similarity measures or similarity scores to indicate quantity and/or quality of matching between the individual ones of the wells and the different locations within the simulated subsurface region;

arrange the similarity maps based on the spatial arrangement of the wells such that the similarity maps overlap with each other within an overlap area, wherein locations within the overlap area correspond to groupings of matched simulated wells, individual groupings including a matched simulated well for individual ones of the wells; and

determine correlation between the wells based on the simulated correlation between the matched simulated wells.

2. The system of claim 1, wherein the subsurface representation includes a computational stratigraphy model rep-

resentation, and the correlation between the wells include chrono-sequence stratigraphic correlation.

3. The system of claim 1, wherein generation of the similarity maps includes determination of locations at which the matched simulated wells are to be located for portions of the similarity maps.

4. The system of claim 3, wherein the portions of the similarity maps include regions of the similarity map within boundaries for corresponding locations.

5. The system of claim 4, wherein the boundaries for the corresponding locations are defined by a symmetrical shape including the corresponding locations.

6. The system of claim 5, wherein the shape including the corresponding locations are defined by a radius around the corresponding locations.

7. The system of claim 3, wherein the locations at which the matched simulated wells are to be located are determined based on the similarity measures or the similarity scores between individual ones of the wells and different locations within the portions of the similarity maps.

8. The system of claim 1, wherein the arrangement of the similarity maps includes the similarity maps displaced from a rotation center location to match displacement of corresponding wells from the rotation center location.

9. The system of claim 7, wherein rotation of the similarity maps about the rotation center location changes the arrangement of the similarity maps and the overlap area covered by the similarity maps, changes to the overlap area resulting in changes to the groupings of matched simulated wells corresponding to the locations within the overlap area.

10. The system of claim 1, wherein the spatial arrangement of the wells is changed by flipping locations of the wells about a line, changes to the spatial arrangement of the wells resulting in changes to the arrangement of the similarity maps.

11. A method for correlating multiple wells, the method comprising:

obtaining subsurface representation information defining a subsurface representation, the subsurface representation defining simulated subsurface configuration of a simulated subsurface region including simulated wells, the simulated subsurface configuration of the simulated subsurface region defining simulated correlation between the simulated wells;

obtaining well information, the well information defining subsurface configuration of wells and spatial arrangement of the wells;

generating similarity maps for the wells based on comparison of the subsurface configuration of the wells with the simulated subsurface configuration of the simulated subsurface region, individual similarity maps characterizing extent of similarity between individual ones of the wells and different locations within the simulated subsurface region, wherein the individual similarity maps characterizing the extent of similarity between the individual ones of the wells and the different locations within the simulated subsurface region includes the individual similarity maps including similarity measures or similarity scores to indicate quantity and/or quality of matching between the individual ones of the wells and the different locations within the simulated subsurface region;

arranging the similarity maps based on the spatial arrangement of the wells such that the similarity maps overlap with each other within an overlap area, wherein locations within the overlap area correspond to group-

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ings of matched simulated wells, individual groupings including a matched simulated well for individual ones of the wells; and

determining correlation between the wells based on the simulated correlation between the matched simulated wells.

12. The method of claim 11, wherein the subsurface representation includes a computational stratigraphy model representation, and the correlation between the wells include chrono-sequence stratigraphic correlation.

13. The method of claim 11, wherein generating the similarity maps includes determining locations at which the matched simulated wells are to be located for portions of the similarity maps.

14. The method of claim 13, wherein the portions of the similarity maps include regions of the similarity map within boundaries for corresponding locations.

15. The method of claim 14, wherein the boundaries for the corresponding locations are defined by a symmetrical shape including the corresponding locations.

16. The method of claim 15, wherein the shape including the corresponding locations are defined by a radius around the corresponding locations.

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17. The method of claim 13, wherein the locations at which the matched simulated wells are to be located are determined based on the similarity measures or the similarity scores between individual ones of the wells and different locations within the portions of the similarity maps.

18. The method of claim 11, wherein the arrangement of the similarity maps includes the similarity maps displaced from a rotation center location to match displacement of corresponding wells from the rotation center location.

19. The method of claim 17, wherein rotation of the similarity maps about the rotation center location changes the arrangement of the similarity maps and the overlap area covered by the similarity maps, changes to the overlap area resulting in changes to the groupings of matched simulated wells corresponding to the locations within the overlap area.

20. The method of claim 11, wherein the spatial arrangement of the wells is changed by flipping locations of the wells about a line, changes to the spatial arrangement of the wells resulting in changes to the arrangement of the similarity maps.

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